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# THE GEOLOGICAL STRUCTURE OF THE SUNDAY LAKE AREA, GOGEBIC COUNTY, MICHIGAN

By

WILLIAM GILCHRIST PEARSALL

A Thesis Submitted for the
Degree of Master of Science

University of Wisconsin

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# CHAPTER I.

## Geography and Topography.

The area under consideration in this thesis consists of sections 7, 8, 9, 16, 17, 18, T. 47 N., R. 45 W., and sections 12 and 13, T. 47 N. R. 46 W., Gogebic county, Michigan. This area is bounded by hills on the north, west and south, and to some extent on the east. There is also a line of hills within the area in the eastern part. The area is, for the most part, low and rather flat. In the central part of the district is Sunday Lake, directly west and southwest of which is a broad stretch of low marsh. The principal topographic features are dependent upon the relative resistance of the different formations.

## CHAPTER II.

### General Geology.

The Gogebic Range consists essentially of a monoclinal succession, the upper members dipping, on the average, about 65° to the northwest, and striking about N. 70° E. The basement consists of Keewatin greenstone and green schist intruded by Laurentian granites and gneisses. Upon this rests unconformably the Lower Huronian which consists of two conformable formations, -- the Sunday quartzite below and the Bad River limestone above, both of which are thin and not very widely distributed through the range. The Middle Huronian does not appear in the district. Unconformable on the Bad River limestone is the Upper Huronian, consisting of the Palms formation, the Ironwood formation, and the Tyler slate. At the base of the Upper Huronian is the Palms formation consisting of a thin conglomerate below and clayey slate and quartzite above. Its thickness is 400 to 500 feet for most of the district, but it is as high as 800 feet thick east of Sunday Lake. It extends throughout nearly the entire district, striking on the average about N. 70° E., and dipping from 40° to 70° N. though usually the dips are 55° to 65° N. Conformable on the Palms formation is the Ironwood formation. The change from the Palms to the Ironwood formation is very

abrupt. This formation consists mainly of slaty and cherty iron carbonate and ferro-dolomite, ferruginous slates and ferruginous cherts, actinolitic and magnetic slates, and black slates. The formation is coextensive with the Palms in distribution, and conformable in strike and dip. For most of the district its width at the surface is 800 to 1000 feet. The Tyler slate is conformable on the Ironwood formation. It consists essentially of mica schists, mica slates, graywackes, graywacke slates and clay slates. It extends from six miles west of Bad River nearly to Sunday Lake, its strike being parallel to that of the Ironwood formation and its dip being 70° to 75° N. Its thickness is 7,000 to 11,000 feet. There are some greenstone intrusives and extrusives of probable Upper Huronian age. Unconformable on the Tyler slate is the Keweenawan consisting of gabbros, diabases, conglomerates, etc. It extends throughout the entire district and has a great thickness. The Cambrian, a sandstone found only in the northeastern part of the district, rests unconformable on the Keweenawan.

A prominent ridge extends along the southern border of the district, and another along the northern border, - both of them striking a little north of east. In the central part of the district the crest of the former is formed by the Archean which borders the Huronian on the south; and at the eastern and western ends of the district, by the iron formation. The latter is formed by the Keweenawan

igneous rocks which border the Huronian on the north. In the central two-thirds of the district the Tyler slate is the site of a low, level, swampy area between the two ridges. A south to north section in the principal part of the district will give an idea of the situation. On the south is

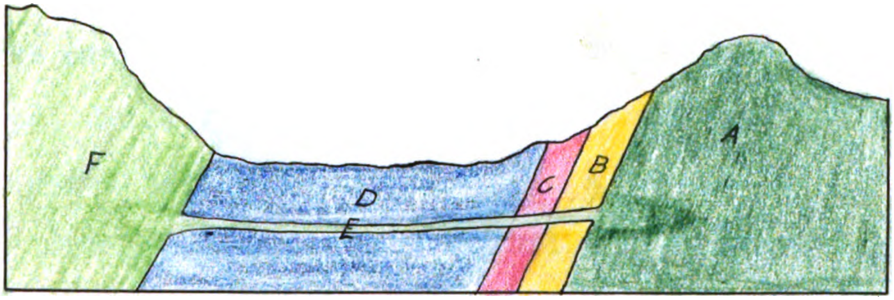


Fig. 1.

a ridge A, whose crest is formed by the Archean, and upon whose north side are the Upper Huronian quartzite and iron formation, B and C respectively. Just north of this, forming the low, level tract D, is the Tyler slate. The ridge, F, north of the Tyler slate, is formed by the Keweenawan lava flows. Cutting the Huronian are large dikes, E, which acted as feeders for the great Keweenawan lava flows.

# CHAPTER III.

## Geology of Sunday Lake Area.

### 1. Distribution of Formations.

The distribution of the various formations in the Sunday Lake area is shown in the accompanying map by means of outcrops, drill records, and mine records; so it will not be discussed here except to mention a few of the more notable facts. The lower and middle Huronian are absent. There is a great widening of the iron formation for a distance of about two miles along the strike, which contrasts strongly with the almost uniform width of the rest of the formation of the entire district. The north edge of the iron formation is in contact with the Tyler slate in the western part of the area and with the Keweenawan in the eastern part of the area, the slate being entirely absent in the eastern part of the area. Drill and mine records show quartzite well up in the non-fragmental iron formation. There is a considerable north-south offset of the quartzite. South of Sunday Lake along the strike of the Upper Huronian the areas of iron formation and quartzite give way to areas of Archean. An eastern continuation of the quartzite and iron formation is found about a mile north where there is an east-west strike, as to the westward. The contact of the

Huronian and Keweenawan is, in general, a nearly east-west line. The Huronian contains abundant intrusives in the form of great, irregular, usually eastward-pitching dikes, and enormous sills parallel to the bedding, most of which are probably of Keweenawan age.

The unusual distribution of the formations in the area indicates a more complicated structure than the rest of the district, and one which requires special explanation. Field work, mine records, and diamond drill records in this area, have established certain definite facts from which we must draw such inferences as best seem to fit the distribution of the various formations in this area. These facts, which deal with lithology, succession, conditions of sedimentation, and structure, will be stated. Then will follow a discussion of the various hypotheses which seem best to fit those facts.

## 2. Lithology and Succession.

A south to north section from Archean to Keweenawan across the quartzite hill east of Sunday Lake was examined as to lithology and succession. In the south part of section 10, T. 47 N., R. 45 W., near the bottom of the quartzite hill an outcrop of greenstone was found, as indicated on the map. It was the typical Keewatin greenstone, -- a fine-grained, dense, green rock.

Directly above was a dark, reddish, medium -grained

quartzite, massive for the most part, but containing some interbedded laminations of more shaly material. Cross-bedding and ripple marks here and in many other places showed very distinctly that the top of the formation was on the north side. Farther north -- on the upper part of the south side of the hill and on top of the hill the quartzite was more finely bedded and more impure, the principal impurity being argillaceous material. Here there was very little massive quartzite. It was mostly thinly laminated shaly quartzite and sandy shale with many alternations of beds of different sorts of material. The thicker beds were nearly all in the form of rather short lenses. Still farther north, on the north side of the hill, there was more of the massive quartzite, which seemed more pure though still dark in color. Here there was very little shaly quartzite. On the whole, the Palms formation here seems to be massive quartzite at the top and bottom. In the middle it was thinly laminated and thinly bedded with beds of varied character.

In the valley north of the quartzite hill the iron formation appeared, extending from the base of the quartzite hill on the south well up toward the top of the hills to the north. It was examined in outcrops, test pits, mine dumps, mines, and drill records; and found to consist esntially of cherty and slaty iron carbonate, ferruginous chert and ferruginous slate, black slate, jasper and hard

and soft ores, all non-fragmental material. The main mass of the iron formation is ferruginous chert, slaty material, and jasper, with occasional pockets or lenses of ore. The iron carbonate is rather scarce in this area. A slight magnetic disturbance also indicated the presence of some magnetite. Drill and mine records show quartzite well up in the iron formation directly west of Sunday Lake. This seems to bethe only place on the Gogebic Range where the quartzite, a fragmental material, is found in the non-fragmental iron formation. Whether the quartzite was originally deposited as part of the iron formation will be discussed later. Going west there was a great thickness of the iron formation which was maintained for nearly two miles, after which it narrowed down to the nearly uniform width found throughout the district. West of a point in the northeast part of Section 7, T. 47 N., R.45 W., the iron formation was overlain by the Tyler slate; while to the east of this point it was overlain by the Keweenawan, the Tyler slate being absent.

The Keweenawan was encountered north of the iron formation, its contact with the iron formation being near the top of the hills north of the quartzite hills. It consisted of typical Keweenawan trap, several distinct flows of which could be distinguished. In the cases of each flow the amygdaloidal texture was very marked near the top and bottom and almost absent in the central part. At the top the amygdules were round, while those near the bottom were distinctly elongated, typical

amygdaloidal texture at the bottom of flows. The traps contained very thin layers of a pinkish, fine-grained rock, much of which was probable quartzite, though some might have been aplite.

Farther west the Tyler slate was found between the iron formation and the Keweenawan. Its different varieties were clay slates, graywacke slates, mica slates, and mica schists. It was everywhere very dark in color.

The three sedimentary formations above mentioned can be readily connected with the three Upper Huronian formations of the rest of the district by their lithology, succession and thickness.

### 3. Conditions of Sedimentation.

The quartzite outcrop was also examined with a view to determining the conditions of its deposition. Cross-bedding and ripple-marks were found abundantly throughout the formation. The formation was, for the most part, of coarse fragmental character. In certain horizons of the formation there were many alternations of thin beds of different character; and here the thicker beds were lense-shaped. The quartzite was very impure throughout. All these things seemed to establish, almost conclusively, the fact that it was largely a shallow water deposit; and possibly, in part, subaerial. It seems probable that this was a beach deposit. The fact that there is no transition phase, but a sudden change, from

quartzite to iron formation, indicates that there was a sudden change of conditions causing deposition of the Ironwood formation and stopping all quartzite deposition. The change from Ironwood formation to Tyler slate is rather gradual; indicating a gradual change of conditions of sedimentation. The iron formation was a non-fragmental material. No evidence was found bearing on the conditions of its original deposition except its non-fragmental character. The theory of its original deposition is discussed in Monograph 52, page 499. The Tyler slate was very dark in color and made up of a poorly assorted material, showing clay and graywacke phases which would indicate that it was probably of shallow-water or sub-aerial origin, probably a great delta deposit.

## 4. Structure.

In this area, as shown in Fig. 2, there is a widening of the iron formation; a considerable north-south offset of the quartzite; an area of ore south of Wakefield with Keewatin greenstone directly east and north of it; an absence of the Tyler slate in the eastern part of the area; a prevalent east-west strike; a flattening and reversing of dip in the vicinity of the Asteroid mine; minor faulting at the Eureka mine.

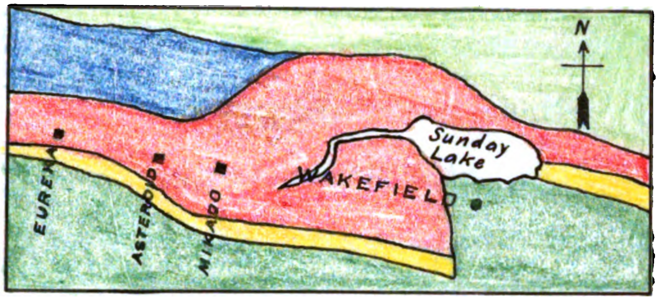
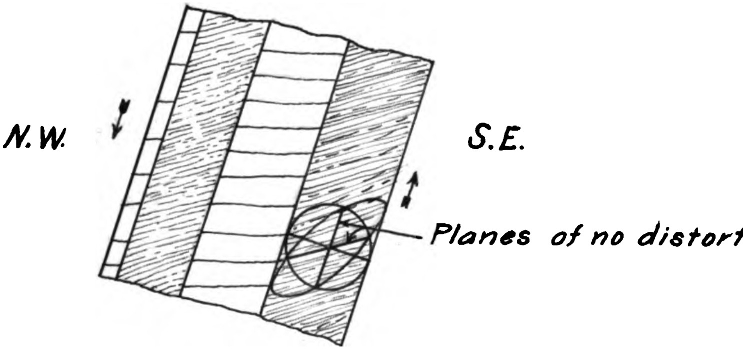


Fig. 2.

The structure of this area, as exhibited in the quartzite hill east of Sunday Lake and in the Keweenawan to the north, was studied in much detail with the object of determining the number and character of the deformations affecting the area. The elements of structure were best seen in the less competent phase of the quartzite,-- the thinly bedded, shaly quartzite which outcrops along the tops of the hills. It was only here that drag folds, cleavage, etc. were developed to any extent. The conspicuous elements of structure were cleavage, folding, faulting and jointing.

The cleavage was more or less parallel to the axial planes of the folds, and was nearly always associated with folds of the parallel type. It was sometimes at a greater angle than 45° with the bedding. Cleavage in softer layers graded into joints in harder layers. The fragments would not split indefinitely into cleavage plates; but split only along certain definite lines spaced some distance apart. There was a lack of recrystallization and development of secondary cleavage, the quartz grains being still rounded

and no new minerals developed. All these facts indicate that the cleavage is fracture cleavage rather than flow cleavage. In the majority of cases the cleavage showed a movement of the present north side in the direction which is now downward and to the northwest as in Fig. 3; while in a number of other cases it showed a movement of the present north beds in a direction which is now upward and to the southeast, as in Fig. 4. For convenience the first of the above movements will be called movement No. 1; and the second movement No. 2.



Fracture Cleavage Passing into Joints.
Fig. 3.

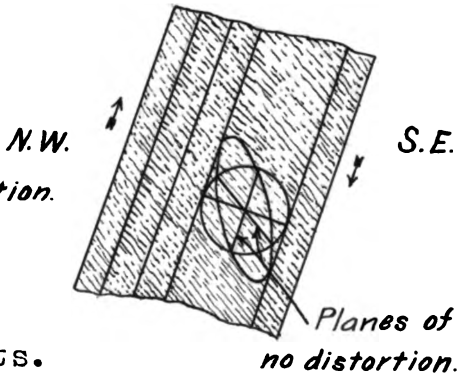


Fig. 4.

In the Keweenawan, the fracture cleavage showed movement only of the latter character. In some cases one cleavage was found superposed on the other, as in Fig. 8.

The folding was of the parallel type, and usually showed a tendency to die out upward along the axial plane in a direction perpendicular to the bedding. The small anticlinoria and synclinoria were practically all of the normal type. The folds often graded into faults along axial planes.

There was an absence of crenulations. These facts together with the presence of fracture cleavage indicate that the folding was in the zone of fracture. The attitude of the drag folds showed two movements - one involving a movement of the present north side in a direction which is now downward and to the northwest, and the other involving a movement of the present north side in a direction which is now upward and to the southeast. These are similar to the two movements shown by fracture cleavage. Figures 5 and 6 are folds whose axial lines pitch about 55° S.E., and whose axial planes dip about 50° N.E. It will be seen by the attitude of the folds that, while the formations were still flat-lying beds from what was originally the southeast direction, they had a tendency to come up over beds to the northwest, as in Fig. 5a, giving a differential movement of the kind shown by the arrows and the strain ellipsoid. This would indicate that the formations had been subjected to a pressure acting in a southeast-northwest direction, resulting in folding and shortening. The thrust would be from the southeast rather than from the northwest because the pitch of the axial lines is toward the southeast.

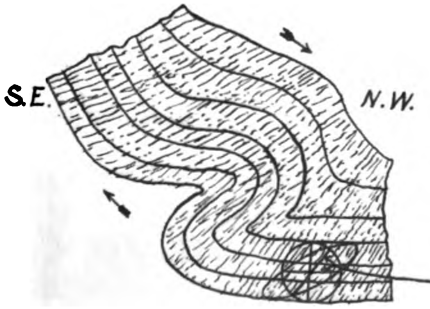


Fig. 5.

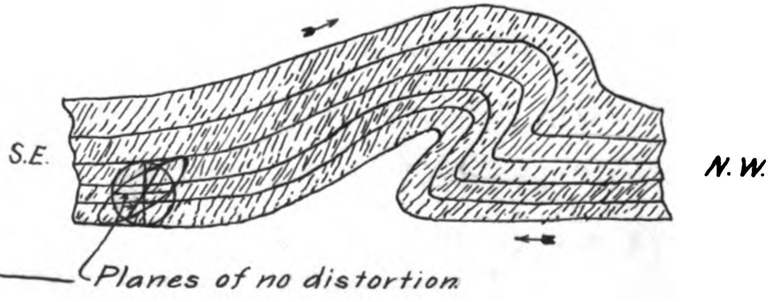


Fig. 5-a.

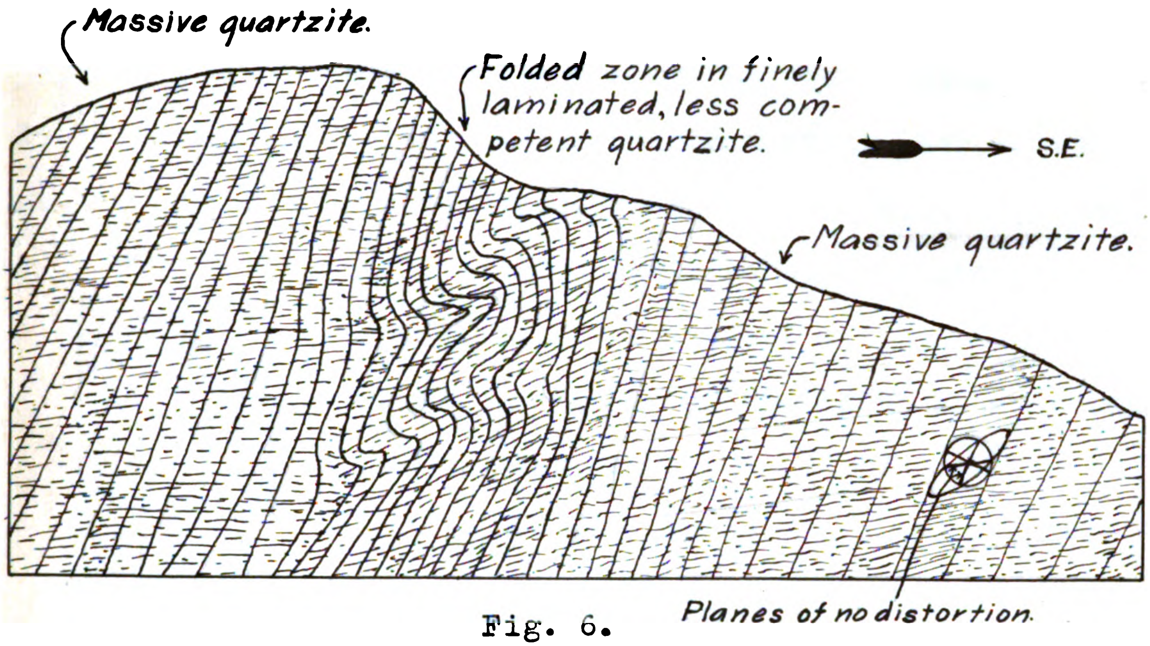


Fig. 6.

The fracture cleavage, as indicated, is parallel to the axial plane. Other drag folds showed an entirely different differential movement, as shown in Figures 7 and 8. Their

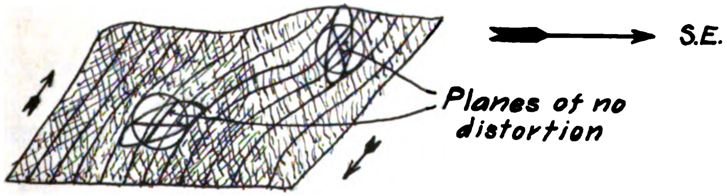


Fig. 7.

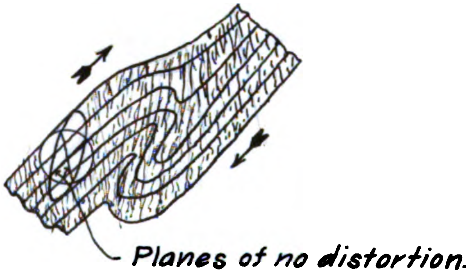


Fig. 8.

axial lines dipped about 20° N.E. and the present north side moved in a direction which is now upward and to the southwest, as indicated by the arrows. This movement, like the other, is shown by the way beds from the northwest side move up and over the bed to the southeast, as shown by the strain ellipsoid.

There was a great deal of faulting on a small scale which, in every case, showed one of the two above-mentioned differential movements. At one place a single bed contained faults produced by both movements as in Figure 9. The fault at A shows a movement of the north side upward to the southeast and the fault at B shows a movement of the north side downward to the northwest.

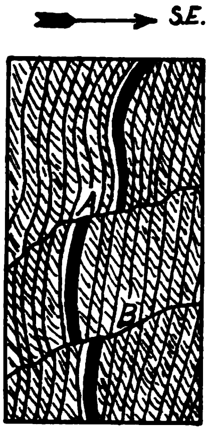


Fig. 9.

There were three principal sets of jointing conspicuous in the area. One set made an angle of 70° with the bedding, being a gradation into the harder beds of the cleavage in the softer beds caused by the movement No. 1. Another and probably complementary, set of shear joints was parallel to the bedding. These two sets of joints were parallel to the planes of no distortion of the movement mentioned above. While these joints were very numerous in the quartzite, they were not found at all in the Keweenawan. The third set of joints seemed to have a general north and south strike, and were found in both the quartzite and the Keweenawan. An irregular jointing was seen in the Keweenawan, probably due to cooling. In some places both in the Keweenawan and the quartzite, there was a set of joints approximately parallel to the fracture cleavage caused by the movement No. 2.

The fracture cleavage, folding, faulting, and jointing

all gave evidence of two differential movements - one involving the movement of the present north side in a direction which is now downward and to the northwest, and the other, the movement of the north side upward and to the southeast. Abundant evidence of both movements was found in the quartzite. In the Keweenawan no evidence was found of the movement No. 1, while jointing and fracture cleavage showed that it had been affected by the other movement. This seems to prove conclusively that the quartzite and those formations conformable with it, while still flat-lying and before Keweenawan time, were affected by a deformation involving a movement of the present north side in a direction which is now downward and toward the northwest. The Keweenawan was then laid down, after which the area was affected by another deformation involving a movement of the north side upward and to the southeast.

The first deformation, as shown by the attitude of the drag folds and the other structural features before mentioned, was a folding or faulting caused by a thrust from the southeast, and involving an east-west shortening. Evidence of east-west shortening was also seen at Penokee gap. Here the drag folds in the quartzite showed a movement of the present north side in a direction which is now downward and to the east, which, while not the same folding as in the Sunday Lake area, still involved east-west shortening.

Several things seem to point to the fact that this deformation was very marked in the Sunday Lake area. The Upper Huronian of the area contains a very great amount of intrusions. The dikes of the Keweenawan age in the Upper Huronian, as shown by mine maps and drill records, instead of being relatively small and regular fillings of joints and fractures, are great,irregular masses indicating a great amount of fracturing during the first deformation. The dikes evidently fill fissures made during the first deformation since they have, in general, an eastward pitch parallel to joints and fracture cleavage cauaed by the first folding. The joints and fracture cleavage, being planes of weakness, would offer an easy path to the dike material. It is probable that there was widespread movement parallel to the bedding. As before mentioned, one principal set of joints, and therefore a set of planes of weakness, of the first deformation, was parallel to the bedding. Throughout the area the mine maps and drill records show enormous sills parallel to the bedding of the Upper Huronian. These have evidently followed the planes of weakness developed during the first deformation. Therefore these great sills might indicate great movement parallel to the bedding. The presence of sills might also be due to duplication of competent layers in the iron formation. The igneous material coming up would strike a competent layer and spread out into a sill. The great ore lenses parallel to the bedding indicate the presence of

planes of weakness favorable to percolating waters. Another evidence that this deformation was considerable and before Keweenawan time is the fact that in the eastern part of the area the thick Tyler slate was entirely eroded off before Keweenawan time, showing that it must have been given very high relief at this point. In short, there was betwean Huronian and Keweenawan time a relatively great deformation,more or less local, which developed conspicuous planes of weakness, some parallel to the bedding, and some dipping in an easterly direction.

The second deformation occurred after the Keweenawan was laid down, since it affected the Keweenawan as well as the Upper Huronian. This deformation is part of a widespread and well-known deformation. The movement of the present north side in a direction which is now upward and to the southeast indicates that it is the deformation which formed the Lake Superior syncline whose axis is parallel to Lake Superior, this being on the south limb of the syncline. It was this folding which gave the Upper Huronian an average dip of about 65° to the north which was noted in many outcrops.

# CHAPTER IV.

## Possible Explanations of the Unusual Distribution of Formations.

No explanation will be advanced as the unquestionable solution of the problem, but certain hypotheses will be discussed which offer possible solutions, which are plausible and simple, and which seem to satisfy the known facts. The principal things to be accounted for, as shown in Fig. 2, are the thickening of the iron formation, the offset of the quartzite, and the fact that, south of Wakefield, there is ore with Keewatin greenstone directly east and north of it, as shown in Fig. 10; the presence of the various horizons of the quartzite within the iron formation; the distribution of the Huronian formations, the presence of great sills and ore lenses parallel to the bedding, indicating planes of weakness parallel to the bedding due to the earlier deformation; a thrust from the southeast involving east-west shortening; deformation of competent beds in the zone of fracture; the fault at the Eureka mine; the flattening of dip at the Eureka and Asteroid mines; and the localization of nearly all the deformation in this particular area.

It was first attempted to explain the structure by

folding and faulting alone, (Fig. 10). The deformation

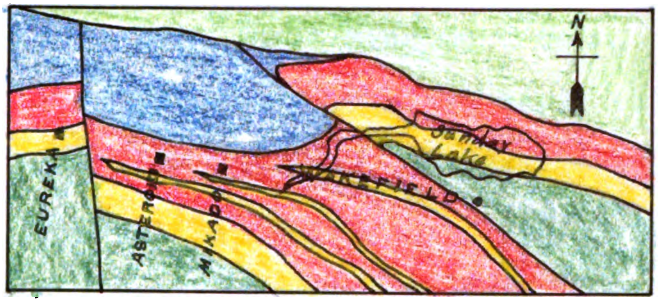


Fig. 10.

would probably be largely by faulting since it occurred in the zone of fracture and both the quartzite and iron formation are very competent. The details of this explanation are shown on map No. 1. A great overthrust fault along the line A-A and considerable imbricated faulting are involved. The overthrust fault would explain the offset of the quartzite and the change from Huronian to Archean along the strike of the former south of SundayLake. This would also give the Tyler slate high enough relief to allow of its being completely eroded off. The imbricate faulting, which would be in harmony with the great planes of weakness parallel to the bedding, and with deformation involving a competent formation in the zone of fracture, would explain the general east-west strike of the Huronian, the thickening of the iron formation, and the presence of quartzite horizons within the iron formation. The thickening of the iron formation might be also due, to some small extent, to the intrusion of the great sills and dikes. The

fault at the Eureka mine, and the distribution of formations in that vicinity, as shown on the map, might be explained by a fault in which the east side went down, thus shoving the Archean and the quartzite farther north relatively in the vicinity of the Eureka mine. The disturbance during the forming of the great overthrust fault to the east might readily cause such a fault, possibly of the tension type, during readjustment. The distribution of formations in the vicinity of the Eureka, might also be explained by imbricate faulting similar to that ascribed to other parts of the area. The flattening of dip at the Eureka and Asteroid mines was possibly due to folding during the latter period of deformation.

Another solution takes into account original sedimentation as well as folding and faulting, (Fig. 11). Original deposition of sandstone beds locally within the Ironwood formation would account for the quartzite in the Mikado mine nearly 2,000 feet north of the main quartzite foot wall, as well as the quartzite within the iron formation in the vicinity of

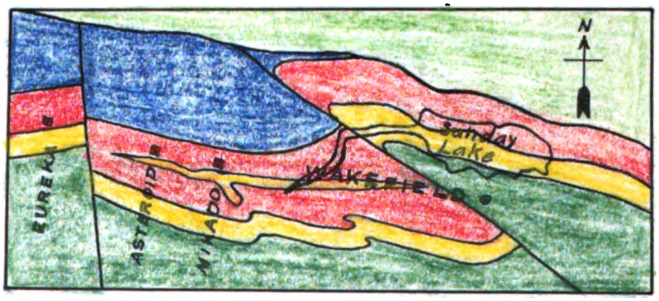


Fig. 11.

the Asteroid and Eureka mines, as shown on the map. The widening of this quartzite horizon near the Mikado mine, as shown in drill holes No. 2 and No. 4 could be explained by a buckle in the formation. This solution would also include the great thrust fault along the line A-A, as indicated on the map. This fault would account for the offset of the quartzite, the unusual position of the Archean with respect to the quartzite and iron formation south of Sunday Lake, and the distribution of the Tyler slate. This would account for the planes of weakness parallel to the bedding as shown by the great sills and areas of concentration parallel to the bedding, since the deformation would produce such planes of weakness as before mentioned. The Huronian formations would retain their east-west strike. The thrust from the southeast involving east-west shortening, and the fact that the deformation was in the zone of fracture, would also be accounted for. The thickening of the iron formation would be due partly to original sedimentation and partly to faulting and folding. It would seem reasonable to expect a continuous and rather regular quartzite footwall, and this solution would give such a footwall, the minor irregularities shown by drill holes No. 12 and No. 14 being explained by small drag folds. The distribution of formations in the vicinity of the Eureka and Asteroid mines might be explained as before or by a drag fold in the main quartzite footwall.

The original deposition of sandstone within the iron

formation seems so out of harmony with the character of the iron formation as known throughout the rest of the district, where it consists wholly of non-fragmental material, that it might be well to discuss the probability of this local difference in original sedimentation. In the first place it seems highly probable that the localization of this great deformation at this particular place would indicate unusual conditions here. Difference in sedimentation might supply these conditions. It is possible that there was a marked depression in the old Archean surface at this point, which would cause unusual conditions of sedimentation and give a greater thickness of the formation. This would also give an initial dip which, possibly in conjunction with unusual conditions of sedimentation, would cause a localization of the deformation at this point. Examination of mine dumps and drill cores showed considerable difference between the main footwall quartzite and the quartzite within the iron formation 2,000 feet north of the main quartzite footwall. Miners who had worked in this area for years, said that the quartzite within the iron formation was in every case harder, "tighter", and more dense than that of the main quartzite footwall. Also fragmental material is actually found in the iron formation farther east. On the whole, a theory based partly on a difference in conditions of original sedimentation would seem quite plausible, and would simplify matters very much.

It is a remarkable coincidence that there should be such a sudden change in the thickness of the iron formation at the fault plane. If the difference in thickness of formations were due to original differences in sedimentation, it would seem reasonable to expect a gradation in thickness instead of the sudden change. However, such a sudden change of thickness would be possible, and might explain the presence of the fault plane at this particular place. The sudden increase in thickness of the iron formation west of the fault plane might be explained by great folding and faulting, so the fact of this sudden change in thickness might favor the first hypothesis.

# CHAPTER V.

## Origin and Metamorphism of the Ore.

The iron formation was laid down as iron carbonate, beds of original chert, slate, and iron oxides, and probably a little greenalite. Then followed the deposition of the Tyler slate conformably on the iron formation. After the deposition of the Tyler slate came the first of the two deformations previously mentioned. An erosion interval followed during which the Tyler slate was entirely eroded off in the eastern part of the area and the iron formation exposed. The exposure of the iron formation, and the fracturing of the formation caused by the deformation in the zone of fracture gave percolating waters ready access to the iron formation. During this period of concentration the iron carbonate and iron oxide of the original iron formation were changed to ferruginous chert and soft ore, the change being more marked in the layers originally rich in iron. This concentration was probably controlled largely by the fissures intersecting, and parallel to, the bedding. A great deal of the ore is found in great lense-shaped bodies parallel to the bedding, -- parallel to one of the principal sets of joints caused by the

earlier deformation. This was followed by the Keweenawan flows which anamorphosed the upper part of the iron formation wherever not protected by the Tyler slate. The ferruginous chert was changed to jasper and the soft ore to hard ore. This almost put an end to the further concentration of ore in this part of the area. Then came the great deformation which formed the Lake Superior syncline. After this came a great erosion interval which again exposed the iron formation, this time throughout the entire district, and the process of secondary concentration has been going on intermittently ever since. That part of the iron formation which was anamorphosed by the Keweenawan lavas has been little affected by this last concentration because of its metamorphosed character. In this area the first concentration was more important. The ore here is due largely to the original richness of the iron formation, and in part to the first concentration. There has been a little concentration here after the last deformation, but it is very slight. Where it has occurred it is controlled largely by the eastward pitching dikes and by intersections of dikes and impervious layers, and by fractures parallel to and intersecting bedding; as in the Brotherton mine. Where the iron formation was covered by the Tyler slate to the westward and therefore was not affected by the earlier concentration and anamorphism, the last erosion period exposes it

for the first time, and here concentration on a large scale has been going on ever since. It was this concentration which has formed all the ore in this part of the district. Here may be seen the iron formation in all its phases, - iron carbonate, ferruginous chert, and soft ore. The concentration is here due to waters following fissures intersecting, and parallel to, the bedding; and by waters following the intersections of dikes and impervious beds. This concentration often occurs on several dikes, one below the other. The secondary concentration is, on the whole, controlled largely by the dikes, although the presence of ore probably depends largely on originally rich iron formation.

## CHAPTER VI.

### Effect of Structure Hypotheses on Exploration for Ore.

Two hypotheses have been advanced to explain the unusual distribution of iron formation in the Sunday Lake area. One involves only folding and faulting, and the other involves local difference in conditions of original sedimentation together with folding and faulting.

1. The first hypothesis developed in this paper to explain the unusual distribution of the formations is that the iron formation is strictly non-fragmental with some horizons originally rich in iron; and that a thrust from the southeast produced a great overthrust fault together with much imbricate faulting, causing great slivers of the main quartzite footwall to come up from the east in such a way as to give horizons of quartzite repeated in a direction which is now north and south with iron formation between. An example of these repeated horizons of quartzite is seen in the vicinity of the Mikado mine, there being a quartzite horizon just south of the Mikado and another several hundred feet farther south, with iron formation between them. These quartzite slivers would probably be confined principally to the southern part of the area. The main quartzite footwall

might be very irregular.

Under this first hypothesis there are three principal factors affecting the localization of ore, - (a) originally rich horizons in the iron formation; (b) pre-Keweenawan concentration; and (c) post-Keweenawan concentration..

(a) Originally rich horizons of iron formation would probably be more important under this hypothesis than under the second hypothesis because in this case there is no fragmental material. Ore due to originally rich iron formation may be looked for in the various horizons of iron formation between the repeated layers of quartzite, such as the iron formation between the quartzite layers south of the Mikado. In fact, any part of the iron formation may contain originally rich horizons.

(b) The pre-Keweenawan concentration may have been more important in the northern part of the area than in the southern part since the former was at the surface at the time of the earlier concentration, while the latter was about a mile and a half below the surface and therefore probably was not much affected by the earlier concentration. In view of the fact that the earlier concentration may have been more important in the northern part of the area, the most favorable places for exploration here would probably be zones of fracturing caused by the first deformation, some of which are parallel to the bedding and some of which inter-

sect the bedding. As this earlier concentration may have slightly affected the iron formation even in the southern part, the above mentioned zones of fracturing might be of minor importance in the southern part of the area. The effects of the earlier concentration probably were felt at greater depths, and therefore probably extend farther south now, under this hypothesis than under the second hypothesis, since under this hypothesis there was greater folding and faulting and therefore greater and deeper zones of fracturing for the circulation of the percolating waters which produced the first concentration.

(c) The post-Keweenawan concentration may have been more important in the southern part of the area, because this part of the area was about a mile and a half below the surface at the time of the Keweenawan lava flows and therefore probably was not much anamorphosed. In view of the fact that the later concentration may have been more important in the southern part of the area, it follows that favorable places for exploration would be along dikes, and the intersections of dikes with impervious layers. The intersections of dikes with various quartzite splinters, which, under this hypothesis, were faulted into the iron formation, would be favorable places for exploration. It is known that the later concentration has had some slight effect upon the iron formation in the northern part of the area. In so far as this is true, dikes might be of minor importance in the northern

part of the area. It is possible that the intrusions have hindered the later concentration in some places. The intrusions have spread out in great sills and dikes in a very irregular manner due to the great amount of fracturing in this area. This extensive and irregular distribution of intrusives would cut up the iron formation into small bands and pieces, thus preventing the ready circulation of percolating waters through the iron formation. This might explain the scarcity of the great lenses of iron ore like those found in other parts of the district.

2. The second hypothesis developed in this paper to explain the unusual distribution of the formations is that the iron formation originally contained layers of fragmental material; and that a thrust from the southeast produced a great overthrust fault together with some minor drag folds. The fragmental material is thought to be confined principally to the southern part of the area. The footwall might be fairly continuous and regular with only minor irregularities due to small drag folds.

Under the second hypothesis, as under the first hypothesis, there are three principal factors affecting the localization of ore: (a) originally rich horizons in the iron formation; (b) pre-Keweenawan concentration; (c) post-Keweenawan concentration.

(a) Originally rich horizons of iron formation would probably not be as important under this hypothesis as

under the first hypothesis, because of the presence of fragmental material. The fragmental material might be distributed in such a manner that the iron formation would be originally rich in iron only in a very few places. In so far as originally rich horizons of iron formation are concerned, it is probable that the northern part of the area is a more favorable place for ore, since the fragmental material seems to be confined principally to the southern part of the area.

(b) As under the first hypothesis, the pre-Keweenawan concentration may have been more important in the northern part of the area since this part of the area was at the surface at the time of the earlier concentration. In view of this fact, the most favorable places for exploration in the northern part would probably be zones of fracturing caused by the first deformation, some of which are parallel to the bedding and some of which intersect the bedding. As under the first hypothesis this earlier concentration may have been of some minor importance in the southern part of the area. Under this hypothesis, as previously stated, it is possible that the effects of the earlier concentration might not be looked for as far south as under the first hypothesis because the less intense fracturing under this hypothesis would not allow percolating waters to penetrate to as great a depth as in the case of the more intense

fracturing under the first hypothesis.

(c) As under the first hypothesis, the post-Keweenawan concentration may have been more important in the southern part of the area for reasons stated under first hypothesis. In view of the fact that the later concentration may have been more important in the southern part of the area, it follows **that** favorable places for exploration are along dikes, and the intersections of dikes with impervious layers. The intersections of dikes with the horizons of quartzite originally deposited in the iron formation, such as that just south of the Mikado, would be favorable places for exploration. Other favorable places might be on the main quartzite footwall or in intersections of dikes with this footwall. It is possible that the dike in the Mikado becomes flat enough to intersect the main footwall at not too great a depth, thus furnishing a favorable place for secondary concentration. As under the first hypothesis, this later concentration may be of minor importance in the northern part of the area. As under the first hypothesis, the distribution of intrusives may interfere with the later concentration, although under the second hypothesis this would not be as great a factor since, with the less intense deformation, there would be fewer zones of fracturing to receive the intrusives.

In general, the principal factor in the localization of ore in this area is the presence of originally rich hori-

zons of iron formation. Secondary concentration seems to have nowhere seriously modified the iron formation. Therefore the most favorable place for exploration would seem to be along continuations of known originally rich horizons, such as in the vicinity of the Mikado mine. This has proved successful in the past. The Mikado mine was at one time abandoned, and further exploration in the mine brought to light a large amount of ore. It is advisable to explore thoroughly in the vicinity of every known ore body in this area. Such places would be the Eureka, Asteroid, Mikado, Pilgrim and the ore body south of Wakefield.

## CHAPTER VII.

### Conclusions.

In the Sunday Lake area a considerable pre-Keweenawan deformation of the Huronian has been localized. This had considerable influence on the distribution of the iron formation and the localization of the ore. Therefore the interpretation of the structural conditions is very necessary in further exploration. Two hypotheses have been advanced which are plausible and simple, and which seem to fit the facts. One of these involves only folding and faulting, while the other involves a local difference in conditions of original sedimentation as well as folding and faulting. Either one furnishes a satisfactory working basis for further exploration.

Approved:

C. K. Leith

Professor of Geology.

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